Sub-resolution feature size classification based on tunable X-ray dark-field imaging

Benjamin K. Blykers, Caori Alejandra Organista Castelblanco, Matias Kagias, Matthieu Boone, Tom Bultreys, Marco Stampanoni, Veerle Cnudde, Jan Aelterman

Pore space properties such as pore shape, connectivity and pore size distribution are key to understanding pore-scale processes. X-ray computed (micro-) tomography (µCT) has become one of the dominant techniques to non-destructively investigate this pore space in three dimensions.

In conventional attenuation-based µCT, the rule of thumb is that the achievable resolution is about three orders of magnitude smaller than the sample size (Cnudde and Boone, 2013). For heterogeneous materials with pores from the nanometer scale up to the millimeter scale (e.g. mineral building materials), this makes it impossible to visualize the entire pore space without taking (multiple) smaller subsamples. This trade-off between image resolution and sample size also forces modelers to make assumptions and generalizations about the unresolved, sub-resolution pore space.

In the last fifteen years, X-ray dark-field tomography has been explored as a technique to overcome this trade-off between resolution and sample size. Dark-field imaging is based on small-angle X-ray scattering (as opposed to X-ray attenuation) and has been shown to be sensitive to sub-resolution density variations (Pfeiffer et al., 2009). Such variations are typically caused by structures of interest like sub-resolution pores, inclusions, micro-cracks and other heterogeneities. Dark-field imaging can be performed using Talbot-Lau grating interferometry, speckle-based imaging, or edge illumination. Although the published research on dark-field imaging is very promising, only limited use cases have been published on quantifying sub-resolution feature sizes (Lynch et al., 2011; Yashiro et al., 2010).

In this work, quantitative information on sub-resolution feature sizes in the nanometer regime has been extracted, based on this dark-field modality of X-ray tomography using Talbot-Lau grating interferometry. A validation experiment was performed at the TOMCAT beamline (Swiss Light Source, Paul Scherrer Institut, Switzerland) (Stampanoni et al., 2007). Alumina particles with either pore sizes of 50 nm or 150 nm were mixed together in a tube with a diameter of 1.5 mm and imaged using grating interferometry at five correlation lengths ranging from 45 nm to 800 nm to cover the pore size ranges. The image voxel size was 1.62^3 μm^3. With conventional absorption µCT, it was not possible to distinguish particles with different pore sizes due to their very similar density. However, the behavior of the particles' dark-field response over the range of correlation lengths allows to classify sub-resolution pore sizes. This suggests that dark-field imaging can be calibrated to quantify sub-resolution feature sizes inside porous materials, overcoming the resolution limitations of µCT.

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